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MOTT MECHANISM AND ANOMALOUS CHARMONIUM SUPPRESSION

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Abstract

We investigate a scenario where conditions for Mott dissociation of charmonium are fulfilled locally in ultrarelativistic heavy ion collisions at the short time scales before hadronization and study possible consequences to be drawn from observation of "anomalous" thresholds in the J/ψ suppression pattern. We suggest that for a compilation of experiments with different kinematics, variables presently in use to display the observed suppression pattern should be rescaled by the γ factor of the $c\bar{c}$ state relative to the participant center of mass. This systematics can be tested by inverse kinematics experiments as, e.g., Pb-S collisions and by sampling data sets in p_T and y of the dimuon pairs.

1 Introduction

Recently, an "anomalous" threshold behaviour in the centrality dependence of J/ψ suppression has been observed by the NA50 experiment [1] in Pb-Pb collisions at 158 A GeV/c. It has been speculated that this indication of a critical behaviour might signal quark-gluon plasma formation [2, 3] as suggested earlier by Matsui and Satz [4] to be a consequence of the Mott mechanism for charmonium bound states in a plasma.

Properties of bound states are modified in dense matter. Above critical densities $n_{\rm Mott}$ (temperatures $\rm T_{Mott}$) they undergo a Mott transition to unbound (but correlated) states in the continuum. For ground state hadrons as light quark bound states this transition corresponds to the phase transition from hadronic to quark matter [5]. For the deeply bound J/ψ at this transition there is still an energetic threshold to be overcome either by kinetic hadron or parton impact or by further compressing and heating the plasma [6, 7, 8, 9]. In this contribution, we want to investigate a scenario where conditions for Mott dissociation of charmonium are fulfilled locally at the short time scales before hadronization sets in and study possible consequences for the NA50 experiment.

2 Mott dissociation of heavy quarkonia *

In order to determine the critical density $n_{\rm MOTT}(Q\bar{Q}^*)$ at which the $Q\bar{Q}^*$ pair will not evolve into quarkonium but rather dissociate into a pair of heavy mesons, we employ here the heuristic criterion that at this density the nearest neighbor for a given heavy quark Q is not a heavy antiquark $\bar{Q}$ but a light antiquark $\bar{q}$ of the medium [7]. According to elaborated quantum mechanical approaches [11, 12], at short time scales $\tau < \tau_{\rm f}$ after the creation and color neutralisation, the heavy quark pair evolves like a diverging wave packet

$$< r^2 >_{Q\bar{Q}^*} (\tau) =< r^2 >_{Q\bar{Q}} (\tau/\tau_{\rm f})^\beta, \tag{1}$$

until it reaches the asymptotic value $< r^2 >_{Q\bar{Q}}$ of a quarkonium state in free space, we take $\beta = 2$ [9, 13]. The mean squared distance of a heavy-light quark pair is obtained from the nearest neighbor distribution function [7] for a plasma density which is proportional to the participant density $n_{\rm part}(t)$ measured in the c.m.s. proper time

$$< r^2 >_{Q\bar{q}^*} (\tau) = {\rm const}/n_{\rm part}(\tau\gamma) \ , \tag{2}$$

where τ is the time in the rest system of the quarkonium* and the γ factor

$$\gamma = \sqrt{\cosh^2(\Delta y) + p_T^2/M^2_{\mu^+\mu^-}} \tag{3}$$

takes into account that the $Q\bar{Q}^*$ state is Lorentz boosted relative to the c.m.s. of the participants. The difference in the γ- factors of S-U and Pb-Pb collisions to be discussed in Sect. 3 is mainly due to different central rapidities of about $y_c = 2.4$ and $y_c = 3.0$, respectively, in the rapidity shift $\Delta y = y_c - y_{\mu^+\mu^-}$.

During the phase when $n_{\rm part}(t)$ rises to its maximum at $t_0 = \tau_0\gamma \sim 1$ fm/c, it eventually exceeds the critical MOTT density $n_{\rm MOTT}(Q\bar{Q}^*)$ for which $< r^2 >_{Q\bar{q}^*} =< r^2 >_{Q\bar{Q}^*}$ and instead of a quarkonium state a pair of heavy mesons will emerge from that region in the reaction plane for which

$$n_{\rm part}(\mathbf{b},\mathbf{s}) > n_{\rm MOTT}(Q\bar{Q}^*) = \gamma^\beta n_{\rm MOTT}(Q\bar{Q}) \ , \tag{4}$$

where $n_{\rm MOTT}(Q\bar{Q}) = {\rm const}\ (\tau_{\rm f}/t_0)^\beta / < r^2 >_{Q\bar{Q}}$ is the critical MOTT density for a $Q\bar{Q}^*$ pair created at rest in the medium ($\gamma = 1$). In Fig. 1, we demonstrate for $\beta = 2$ that the occurence of “anomalous” behaviour (Mott effect) in a given nucleus-nucleus collision depends on the kinematical conditions. The dependence on the scaled variable $n_{\rm part}/\gamma^\beta$, however, is expected to uncover the threshold behaviour due to the Mott dissociation.

*The asterix indicates that the $Q\bar{Q}$ state is a color singlet but not yet a state of the charmonium spectrum and will be denoted as *in statu nascendi*, see [10].

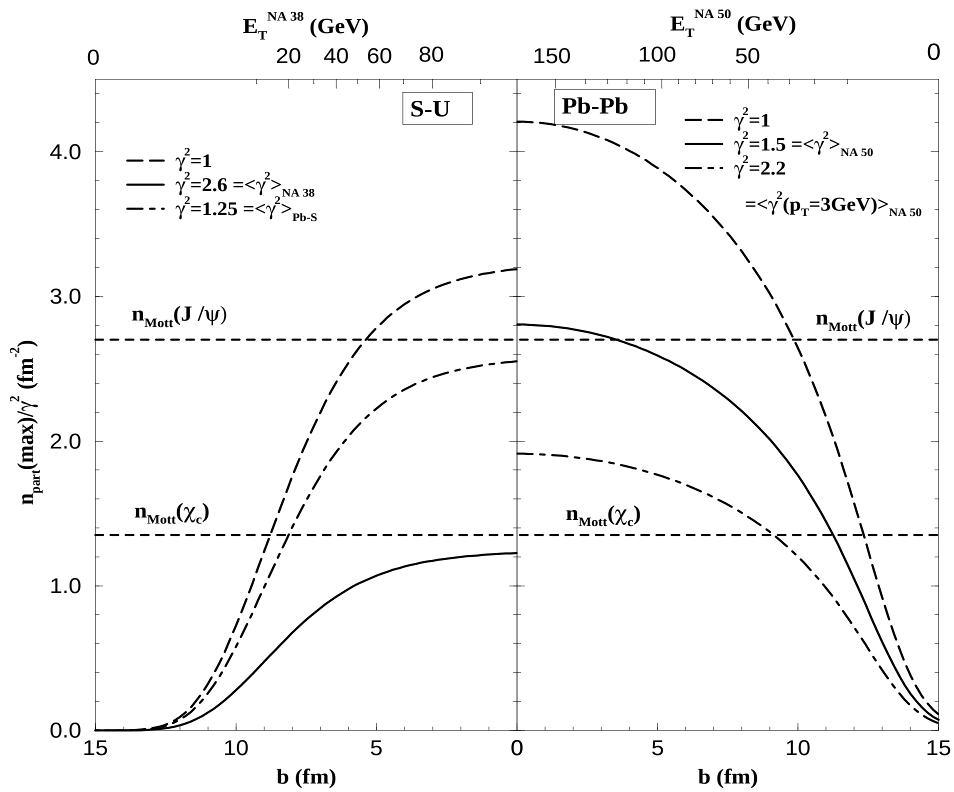

Fig. 1. Criterion for Mott-dissociation of charmonium states. Central participant densities (long dashed lines) as a function of the impact parameter b (bottom scale) or equivalently the transverse energy E_T (top scale) have to be scaled by the γ- factor of the charmonium Lorentz-boost relative to the c.m.s. of the collision, since the sizes of the charmonia *in statu nascendi* at τ_0 depend on γ. Solid lines correspond to the present data of the S-U (left panel) and the Pb-Pb (right panel) experiments, resp. The horizontal dashed lines show the critical MOTT densities which mark the onset of "anomalous" suppression as observed in the Pb-Pb experiment.

3 Glauber model for anomalous J/ψ suppression

Previous analyses of J/ψ production in pA as well as AB collisions within the Glauber model have shown [3, 14] that nuclear absorption gives a satisfactory description of J/ψ suppression data except for the recent Pb-Pb data sample [1] which therefore has been termed "anomalous". The relevant quantity in this description is the survival probability $S_{\rm nucl}(b) = \int d^2\mathbf{s}\ S_{\rm nucl}(\mathbf{b}, \mathbf{s})$ for a J/ψ formed in an AB collision at impact parameter $b = |\mathbf{b}|$ which is an integral

over the survival probability density [16]

$$S_{\rm nucl}(\mathbf{b},\mathbf{s}) = \frac{(1-(1-\sigma_{\rm abs}T_A(\mathbf{s}))^A)(1-(1-\sigma_{\rm abs}T_B(\mathbf{s}-\mathbf{b}))^B)}{\sigma_{\rm abs}^2\ AB\ \int d^2\mathbf{s}\ T_A(\mathbf{s})T_B(\mathbf{s}-\mathbf{b})} \tag{5}$$

in the transverse plane. T_A (T_B) is the nuclear thickness function for a Woods-Saxon density distribution of the target (projectile) nucleus normalized to unity. A cross section $\sigma_{\rm abs} = 7.3$ mb which is compatible with pA data gives an excellent description of J/ψ production in AB collisions as performed by the NA38 experiment. For Pb-Pb collisions the nuclear absorption (5) alone fails to describe the data, see Fig. 2. Additional comover absorption [15] does not give an overall satisfactory description of the whole data sample even if a continuous increase of the absorption cross section with $n_{\rm part}$ is assumed, see also [3].

The rather pronounced threshold observed in the Pb-Pb data hints at a critical behaviour as, e.g., predicted by the MOTT dissociation effect considered in the previous Section. We want to implement this effect into the Glauber model approach by cutting those regions off the reaction plane where the MOTT condition (4) is fulfilled. Considering a 30% feeding of the observed J/ψ from decays of χ_c and neglecting the small correction for ψ' we obtain the total J/ψ survival probability

$$\begin{aligned} S(b) &= 0.7\ S_\psi(b) + 0.3\ S_\chi(b) \\ S_i(b) &= \int d^2\mathbf{s}\ S_{\rm nucl}(\mathbf{b},\mathbf{s})\ \Theta[n_{\rm part}(\mathbf{b},\mathbf{s}) - \gamma^\beta n^{\rm MOTT}(i)]\ . \end{aligned} \tag{6}$$

According to the Glauber model the density of participants in the transverse plane for a given impact parameter is $n_{\rm part}(\mathbf{b},\mathbf{s}) = AT_A(\mathbf{s})(1-(1-\sigma_{\rm inel}T_B(\mathbf{s}-\mathbf{b}))^B) + BT_B(\mathbf{s}-\mathbf{b})(1-(1-\sigma_{\rm inel}T_A(\mathbf{s}))^A)$. The total survival probability (6) is a generalization of equations employed in Refs. [2, 3]. The main difference is that in Eq. (6) we account for the fact that suppression of quarkonia *in statu nascendi* depends on the time scales involved. Consequently, the critical Mott-densities (4) have to be rescaled with the γ-factor (3) which implies a dependence on the rapidity shift Δy and the transverse momentum p_T at which the dimuon pair is detected. In order to use different experimental situations for a more precise determination and identification of the thresholds, it is necessary to define a variable respective to which the threshold behaviour appears universal. After inspection of Eq. (6) we propose here the scaled variable $< n_{\rm part}(b) > /\gamma^\beta$, where the mean number of participants is defined [3] by $< n_{\rm part}(b) >= \int d^2\mathbf{s}\ n_{\rm hard}(\mathbf{b},\mathbf{s})\ n_{\rm part}(\mathbf{b},\mathbf{s})/\int d^2\mathbf{s}\ n_{\rm hard}(\mathbf{b},\mathbf{s})$, and the density of hard collisions is $n_{\rm hard}(\mathbf{b},\mathbf{s}) = A\ B\ T_A(\mathbf{s})T_B(\mathbf{s}-\mathbf{b})\sigma_\psi^{NN}$. The numerical results are shown in Fig. 2.

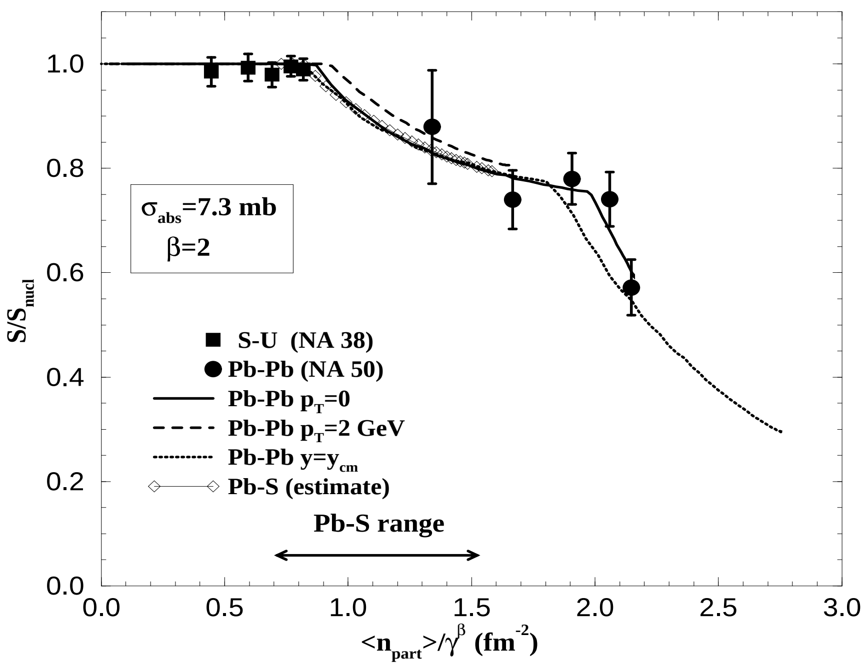

Fig. 2. J/ψ suppression in nucleus-nucleus collisions normalized to pure nucleonic absorption. Whithin our approach, all data should approximately follow a universal curve as function of the averaged participant density divided by γ^β, where the two thresholds correspond to the onset of Mott dissociation for the χ_c and the ψ state, respectively. The open diamonds show an estimate for the result of an inverse kinematics experiment Pb-S which fills the gap between present S-U (filled squares) and Pb-Pb (filled circles) data sets.

4 Conclusions

We have reanalyzed recent data on J/ψ production in S-U and Pb-Pb collisions at CERN-SpS and found that besides conventional sources an additional absorption mechanism with critical behaviour is necessary. In the present work we have generalized the Glauber model approach to J/ψ suppression by implementing the critical Mott dissociation effect for charmonia *in statu nascendi*.

There are new aspects in this analysis: (1) there are two thresholds expected to occur in the "anomalous" J/ψ suppression pattern due to the critical Mott effect for the 1p (χ_c) and the 1s (J/ψ) state; (2) the corresponding threshold values for impact parameter or transverse energy depend on the kinematics of the $c\bar{c}$ pair relative to the hot and dense medium which it experiences *in statu nascendi*; (3) conclusions from J/ψ suppression for the diagnostics of the state of matter (QGP formation) depend on the kinematics. As a consequence, QGP might be present in S-U collisions although J/ψ production as

measured by NA38 at $< \gamma^2 >= 2.6$ is not "anomalous".

In order to investigate the threshold behaviour of J/ψ suppression we have proposed the variable $< n_{\rm part} > /\gamma^\beta$, where $\beta = 2$ is supported by present data. We find it most useful to perform systematic experimental studies by (1) using inverse kinematics (for lead beam on sulphur, see estimate in Fig. 2) and (2) sampling low vs. high p_T and/or low vs. high rapidity bins. These analyses can be performed using data as provided by the NA50 experiment.

The theoretical approach to the kinetics of the hadronization process for a heavy quark pair in a dense plasma has been simplified here by the introduction of an instantaneous breakup. A more detailed investigation is in progress [17].

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